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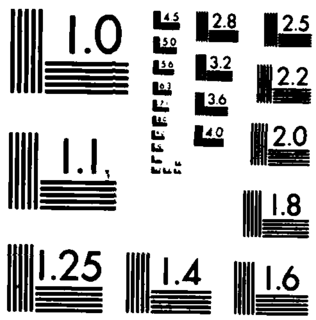
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Report demonstrates that even-mode/odd-mode analysis, used for the design of parallel coupled half-wavelength resonator filters, can be used to design interdigital filters

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PRECISE DESIGN OF INTERDIGITAL FILTERS, USING EVEN MODE/ODD MODE PARAMETERS

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ASD 83 074

Abstract: This paper demonstrates that even-mode/odd-mode analysis, used for the design of parallel-coupled half-wavelength-resonator filters, can be used to design interdigital filters (quarter wavelength resonators, open circuited at one end, short circuited at the other). For an exact design, direct coupling to the input and output resonators must be used. However, with a reasonable approximation, edge coupling can be utilized in place of direct coupling.

Two design examples are given.

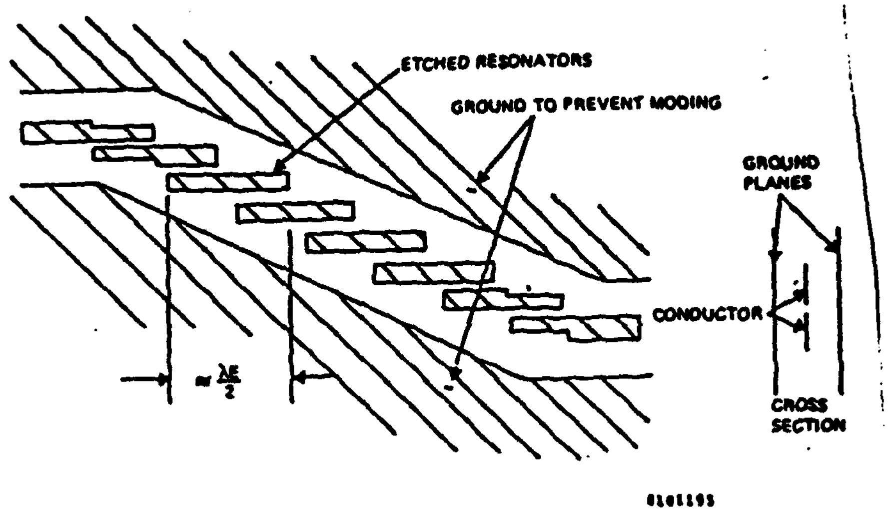
I. INTRODUCTION

Parallel-coupled half-wavelength filters, as shown in Figure 1a and described by Cohn (Ref. 1), are easily designed. Measured performance generally agrees very closely with predicted.

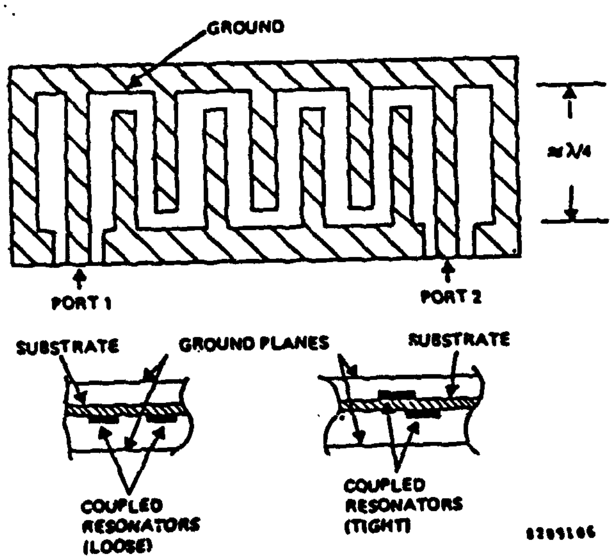
In performing a design study[1] of a SATCOM phased array module requiring precise highly-selective filtering, it was desired that the performance of printed parallel-coupled half-wavelength filters be compared to that of low cost interdigital filters (Ref. 2), illustrated in Figure 1b. Although breadboards of the former were fabricated and matched the desired response nearly exactly, it was found that the latter could not be implemented as precisely.

The primary difference between the design approaches was that even-mode/odd-mode impedances were used to design the parallel-coupled filters, whereas the interdigital filters were designed using estimates of self and mutual capacitances. It was decided to see how the more precise even-mode/odd-mode approach could be applied to the design of interdigital filters.

Ref. 1 -The work presented in this paper was sponsored by the Air Force Wright Aeronautical Laboratories, Avionics Laboratory, Air Force Systems Command, USAF, Wright-Patterson AFB, Ohio 45443, under contract F33615-81-C-1432.



a) Parallel-Coupled Half-Wavelength-Resonator Filter



b) Interdigital Filter

Figure 1. Filters Considered in This Paper

II. DESIGN APPROACH

The design approach is straightforward. Referring to Matthaei, et. al (Ref. 3), it is noted that the susceptance slope for a quarter-wave resonator is half of that for a half-wave resonator of equal characteristic impedance. This means that, to obtain the basic design parameters for an interdigital filter, we would simply use the design equations for a parallel-coupled filter, but substitute "w/2" for "w", where w is the fractional bandwidth desired. That is to say, the design parameters ($w_{j,j+1}$; $s_{j,j+1}$) for a five-percent bandwidth parallel-coupled filter are identical to those of a ten percent bandwidth interdigital filter.

The <u>interdigital</u> design equations are, therefore:

$$\frac{J_{01}}{Y_o} = \sqrt{\frac{\pi w}{4 g_o g_1}} \qquad (1)$$

$$\left.\frac{J_{j,\,j+1}}{Y_o}\right|_{j=1 \text{ to } n=1} = \frac{\pi w}{4\omega'_1} \frac{1}{\sqrt{g_j \; g_{j+1}}} \qquad (2)$$

$$\frac{J_{n,\,n+1}}{Y_o} = \sqrt{\frac{\pi w}{4 g_n \; g_{n+1}}} \qquad (3)$$

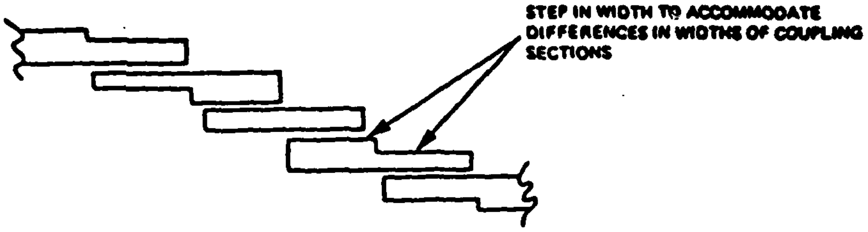
See Ref. (4) for definition of terms.

There is an important practical difference between interdigital and parallel-coupled filters. In the latter, half of the "j^{th}" resonator is coupled to the "$j-1^{th}$" resonator and the other half is coupled to the "$j+1^{th}$" resonator. The resonator width is stepped down when $W_{j-1,\ j}$ is different than $W_{j,\ j+1}$. This is illustrated in Figure 2a.

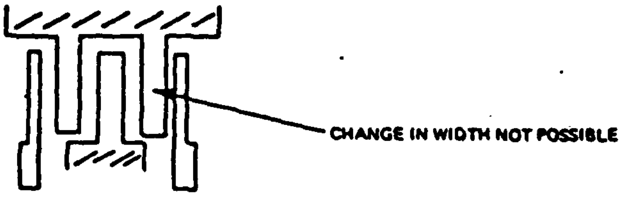
For the interdigital filter, the resonator is only a quarter wavelength, and couples to both adjacent resonators. A reasonable approximation is to set:

$$W_j = \frac{W_{j-1,j} + W_{j,\ j+1}}{2} \tag{4}$$

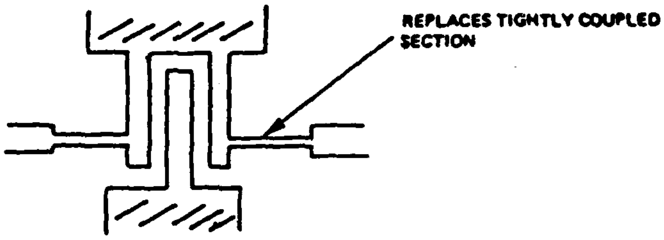
This approximation becomes significant only for the input and output coupling sections. An exact design can be achieved by using direct coupling, as shown in Figure 2c.



a) Parallel-Coupled Filter



b) Interdigital Based on Parallel Coupled



c) Exact Interdigital Filter Based on Parallel-Coupled

Figure 2. Illustration of the One Area Of Non-Equivalence Between the Two Filter Types

III. EXPERIMENTAL RESULTS

To test the even-mode/odd-mode design approach, two filters were fabricated and tested. The first was a five-pole, solid-dielectric L-band filter, with the circuit pattern etched on copper-clad dielectric. The second was a fifteen-pole filter, covering the military SHF SATCOM terminal receive band of 7.25 GHz to 7.75 GHz. It was an "air" stripline design, comprising a circuit pattern etched in brass shim stock, and mechanically supported by low density foam.

L-Band Filter

As the first test, a relatively simple filter was designed. Its parameters were:

Center frequency: 1.0 GHz
Equal Ripple Bandwidth: 80 MHz
Ripple: 0.01 dB
Dielectric Constant: 2.22
Ground plane spacing: 0.125"

The width of the first and fifth resonators was set equal to the average of W_{01} and W_{12}.

The filter dimensions are:

$W_0 = W_6 = 0.083"$
$W_1 = W_5 = 0.092"$
$W_2 = W_3 = W_4 = 0.102"$
$S_{01} = S_{56} = 0.010"$

$S_{12} = S_{45} = 0.056"$
$S_{23} = S_{34} = 0.070"$

Figure 3 is the measured response of the filter. The circled points are the theoretical response, taking into account loss (Ref. 5). Agreement is good. The reduction in attenuation above 1.1 GHz is probably due to moding. Care was taken in grounding the resonators, but additional attention would have to be paid to grounding and mode suppression for application of this filter to a practical system.

SHF Filter

The project under which this work was conducted has been concerned with the design of practical solid state modules for application to full duplex airborne SHF satcom arrays. It has been shown that highly selective filtering is required to permit a transmit power amplifier and receive low noise amplifier to be located in the same module, even with some reasonable polarization isolation. The receive band is 7.25 GHz to 7.75 GHz, while the transmit band is 7.9 GHz to 8.4 GHz. A fifteen-pole preselector is required.

Figure 4 is a photograph of the filter that was designed. Split block construction is used, providing well-defined grounding. The resonators were slightly displaced, laterally, to minimize end loading due to capacitance between the resonators and the side walls. The coupling occurs over less than a quarter wavelength, but this is acceptable because the coupled lines are relatively broadband inverters. The ground plane spacing is only 0.1 inch.

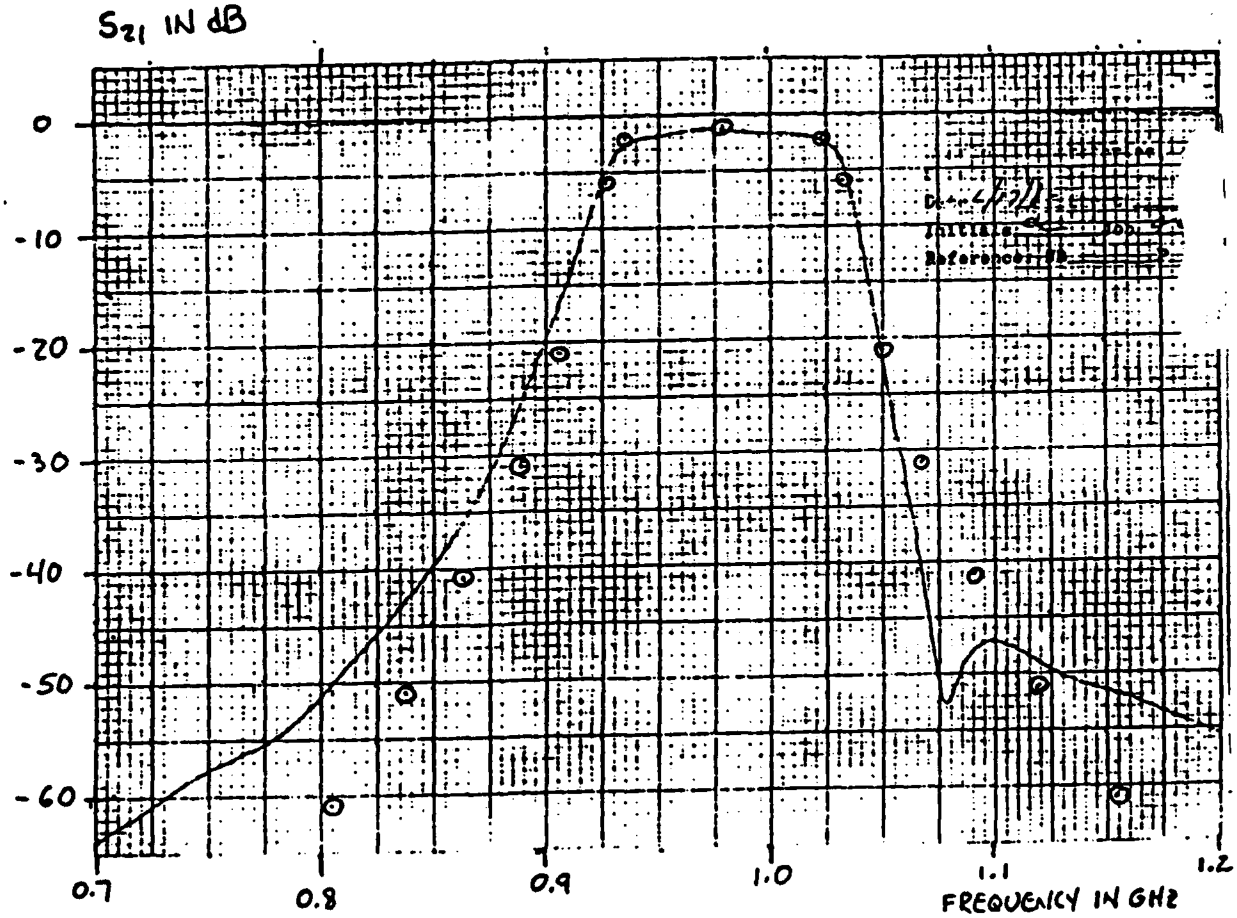


Figure 3. Measured Response of 5-Pole L-Band Filter

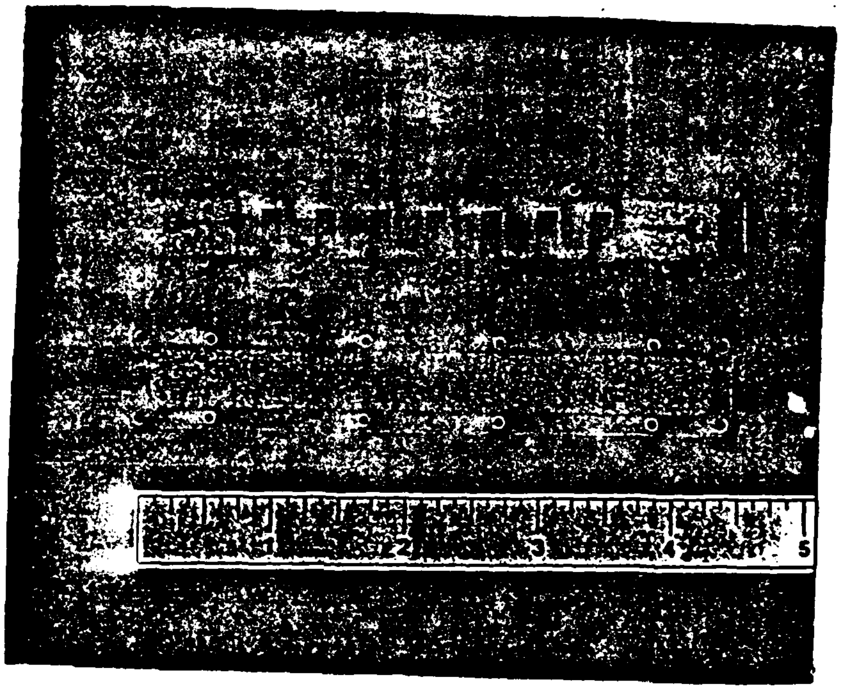


Figure 4
Fifteen-Pole Interdigital Filter for SHF Satcom Receive Band

The circuit pattern was etched from brass shim stock. With this approach, direct coupling is necessary for mechanical integrity. Top launch connectors were used.

Figure 5 is the measured response of the filter. As was expected from the choice of ground plane spacing, the loss is quite high. However, the response shape is excellent. The filter was designed for a center frequency of 7.5 GHz, and an equal-ripple bandwidth of 540 MHz. The dip in insertion loss at midband is caused by high input and output VSWR's. The direct coupling would have to be experimentally optimized to reduce these VSWR's.

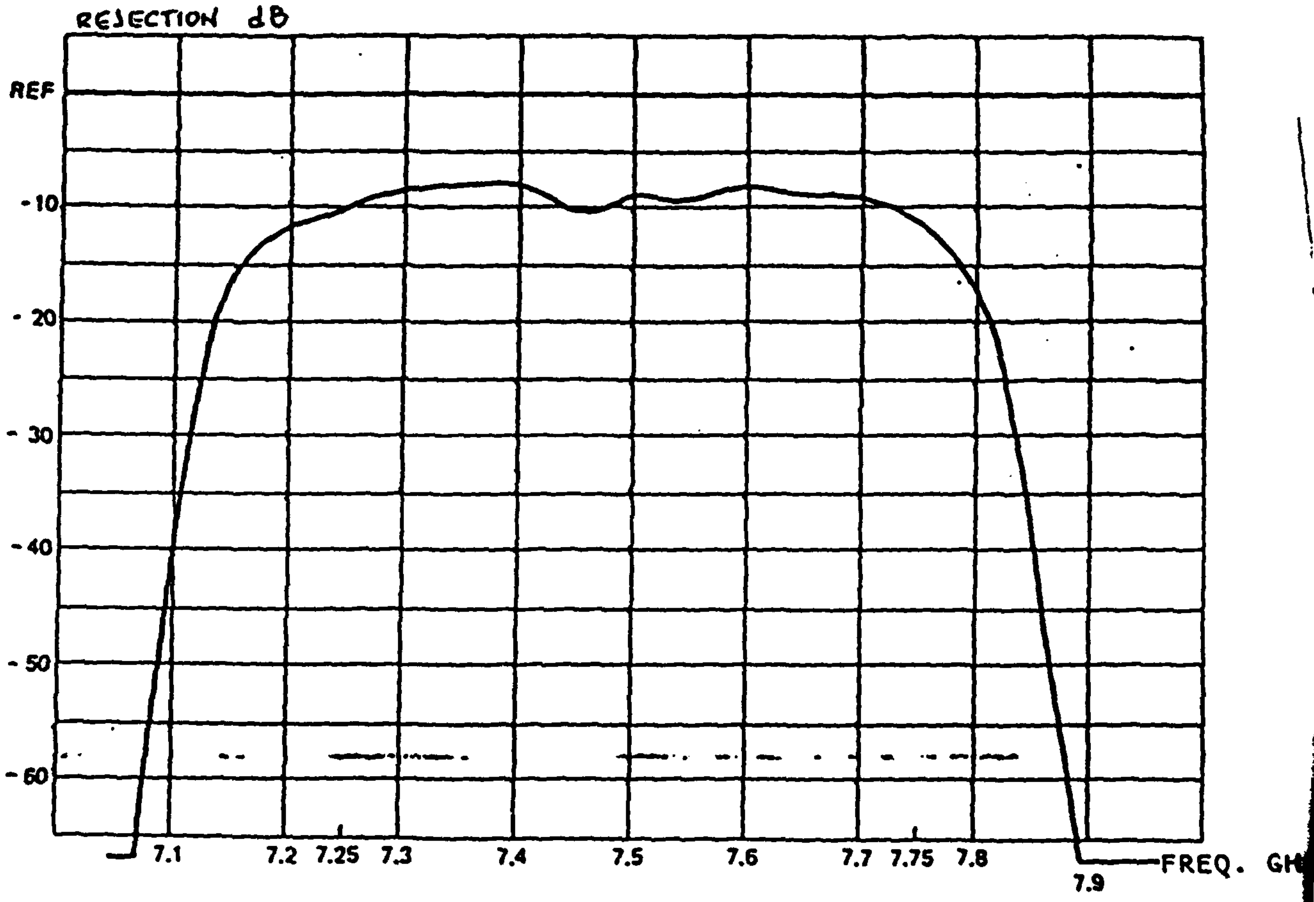


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Figure 5
Measured Response of the 15-Pole Interdigital Filter

IV. SUMMARY

By a straightforward substitution of "w/2" for "w", the design equations for parallel-coupled half-wavelength resonator filters can be applied to the design of interdigital filters. Although the experimental verification of the precision of this approach was confined to filters with resonators of negligible thickness, it would appear that design data for directional couplers having coupling sections of appreciable thickness could be used to improve the precision with which any interdigital filter is designed.

V. ACKNOWLEDGEMENTS

The work reported in this paper has been conducted under the cognizance of Mr. Franklin Lamb of the Air Force Wright Avionics Lab. The invaluable assistance of Mr. Allan Gayer and Mr. Carmelo Cocozzelli is acknowledged.

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